Chapter 8
Discussion
In this thesis, information about the wheelchair-athlete-interaction in wheelchair basketball is studied by means of defining, quantifying, simulating, predicting and optimizing mobility performance. Mobility performance takes into account the individual capacities of the athlete, the possibilities of the material, and the requirements of the environment, and the continuous interaction between them (Figure 1). For wheelchair basketball athletes, the individual adjustment of the wheelchair to the athlete, with their specific impairment and abilities, supplemented with the requirements of the environment (where environment is defined as both the physical and social or game-related environment), are of great importance. To improve mobility performance in wheelchair basketball, understanding of how athletes handle their wheelchair, for instance during actions in matches and the effect of wheelchair adjustments on that, will lead to a better wheelchair-athlete-environment interaction which improves mobility performance and, therefore, game play and team performance. This thesis provides a methodology to understand mobility performance in wheelchair basketball which can be used to further optimize wheelchair-athlete interaction and game performance.

The main findings of this thesis are:

• **Defining** and **quantification** of mobility performance shows that during an entire wheelchair basketball game there are significant differences in mobility performance between national and international playing standards. National players drove more forward and performed fewer rotational movements than international players. Furthermore, it is concluded that the environmental characteristics offense, defense, and ball possession influenced mobility performance for the different field positions guard, forward and centre differently.

• To **simulate** mobility performance in a controllable setting, the field-based Wheelchair Mobility Performance (WMP) test is developed based on the quantification of the observed game behavior data. This led to a set of 15 test parts and a total overall test performance time score. The construct validity, reliability and sensitivity to change indicated that the overall performance time on the WMP-test can be used to monitor and assess mobility performance of individual athletes.

• A **prediction** study indicated eight wheelchair-athlete characteristics as a predictor for mobility performance. Six of these performance determinants are modifiable and can be

Figure 1. Mobility performance in wheelchair basketball consists of three aspects; the athlete, the wheelchair, the environment and the continuously interaction between them.
employed both in individual training (maximal isometric force) and wheelchair adjustments (wheel axis height, handrim/wheel diameter, camber angle, vertical distance between shoulder and rear wheel axis (seat height) and the vertical distance between the front seat and the footrest).

- A first exploration on optimizing mobility performance showed in improvement in overall mobility performance on the WMP test when the seat height was 7.5% lower than the athletes’ common seat height. No differences in performance time were observed with 7.5% extra mass or additional grip.

8.1 Defining and quantifying mobility performance

In order to define and quantify mobility performance it was necessary to get an overview of the game activities of the wheelchair-athlete combination and the influence of the environment on that during match play. The studies in Chapters 2 and 3 give an extensive overview of wheelchair-athlete activities during wheelchair basketball matches. Besides observation of all the wheelchair-athlete actions, comparisons between field positions, classifications and playing standards were performed. The influence of the environment, in terms of individual ball possession and offense/defense, gives additional relevant information. Time-motion video-analysis was used to observe the different aspects of mobility performance. The developed observation scheme to observe mobility performance, contained all possible characteristics of mobility performance that were observable with video-analysis. However, the used video-analysis system does not provide insight into all aspects of mobility performance. More specific information about the wheelchair (e.g. kinematic/kinetic outcomes), the environment (e.g. actual field position) and the athlete (e.g. trunk movement) cannot be retrieved with the used method. Kinematic and kinetic outcomes can be derived from a new method using inertial sensors: “the wheelchair mobility performance monitor” (87). This method provides detailed quantification of selected kinematic and kinetic outcomes of the wheelchair which discriminate well between wheelchair basketball athletes of different playing standards. However, these results give only an overview of the wheelchair kinematic outcomes averaged over the entire match. Specific information about how athletes handles their wheelchair and the influence of the environment, for example ball possession, is not incorporated. The observation scheme of mobility performance described in Chapter 2 should be combined with the kinematics outcomes like linear and rotational speeds and accelerations. Another potential improvement would be the use of an indoor tracking system for wheelchair court sports that provides position data of the athlete in the playing field (68). Position data is also a part of mobility performance which enables tactical team analyses. The indoor tracking system enables the wheelchair mobility performance analysis to be split by environment specific characters such as offense and defense. One of the studies from the project parallel to this project by van der Slikke et al. (88) combined the inertial sensor method, which is described above, and the indoor tracking method. Van der Slikke et al.
reminded this hybrid solution as the new standard for mobility performance measurements in wheelchair court sports. However, specific information about wheelchair-athlete actions and ball possession is missing in both systems. It is recommended to combine these methods with the video-based studies in Chapter 2 and 3.

In the used observation scheme, not only the wheelchair movements were observed, also the way the wheelchair is handled by the athlete. For example, driving forward with 1 or 2 hands or otherwise. This athlete information is not complete. Athletes who can, used their trunk as well in manoeuvring the wheelchair. Information about trunk movements in the frontal and sagittal plane could provide insight in propulsion during wheelchair movements. Trunk motion in the frontal and sagittal plane can, in principle, be measured with an inertial sensor on the back of the trunk. The validity and reliability of this system should be determined during games, so that trunk motion can be included in mobility performance observation to get a full overview about how athletes handle their wheelchair. Furthermore, trunk motion is a key-factor in the current classification system. Further information about trunk motion during match play could provide insight in the validity of the current classification system.

In sum, to get a total overview of mobility performance, additional information needs to be added to the current video-based system used to define and quantify mobility performance during wheelchair basketball. In order to accomplish this, the video-analysis method, inertial sensors method and indoor tracking methods should be combined. Integration and synchronization of the three methods is of great importance so that they can fortify each other. For the inertial sensor and indoor tracking method, expensive material and specific knowledge is necessary to perform and analyze the measurements. In contrast, the used video-analysis system in this thesis requires little and cheap material compared to the other systems and requires less specific knowledge. Therefore, despite being time-consuming, the observation method and scheme can be used well by trainers and coaches to gain insight in mobility performance in their individual players and team in a relatively easy way.

8.2 Simulating mobility performance
Assessing mobility performance is a fundamental requirement for trainers, coaches and wheelchair technicians to, for example, develop training schemes, discuss and improve the athlete’s level of performance, detect strength and weaknesses, and to adjust wheelchair settings. In order to repeatedly monitor and assess athletes’ mobility performance in a controllable setting, the continuously changing environmental aspects must be excluded. Therefore, the Wheelchair Mobility Performance (WMP) test for wheelchair basketball players was developed (Chapter 4) which simulated the most common wheelchair-athlete activities during matches in a standardized test.
To simulate mobility performance as described in Chapter 4, a field test was developed in which wheelchair-athlete activities were selected and combined that were most common during match play video analyses, supplemented with kinematics results from the study of van der Slikke et al. (87). The developed WMP test meets the requirements which have been reported in previous studies of wheelchair court sports (38,53,96). The test is easy to perform for athletes and only common materials such as a ball, cones and a stopwatch are required. This test can be used in several ways: as a standardized mobility performance test to assess the capacity of mobility performance of athletes, their performance transitions over time or to investigate the effects of adjustments of the wheelchair setting. To date, the wheelchair fitting process for performance optimization is highly dependent on the experience level of athlete and/or the wheelchair technician and the WMP test can be used to objectively measure (potential) effects of wheelchair-athlete adjustments on mobility performance.

The used outcome measure of the WMP test in this thesis is performance time in seconds. Performance time is easy to measure and, therefore, the test can easily be used in practice. Unfortunately, for small and short (rotational) movements, performance time showed low reliability and construct validity. However, these actions are frequent elements of mobility performance during wheelchair basketball matches and, therefore, important to include in the WMP test. As a general outcome of the WMP-test only the performance time on the 3-3-6m sprint, the combination task and the overall performance time are recommended to be used in both practice and research. The test results could be combined with the “wheelchair mobility performance monitor” which provide six valuable kinematic outcomes (87).

The current WMP test is based on extensive overviews of wheelchair-handling activities during wheelchair basketball. Because of this, the test is not expected to be representative for other wheelchair court sports like tennis or rugby, because it is plausible that the wheelchair-athlete-environment activities are different for these different court sports. It is advised to use the described methods to develop, understand and simulate the sport-specific requirements of mobility performance in the different wheelchair (court) sports. This method has previously also been used for daily life wheelchair users (34) or in other domains. For example, the physical test for Dutch police officers is based on the method of defining and quantifying (60). In general, to assess performance, it is necessary to understand the (sport)- specific requirements through intensive observation independent of the domain.
8.3 Predicting and optimizing mobility performance
Several wheelchair-athlete characteristics will influence mobility performance (Figure 2). Most studies related to mobility performance have focused on the effect of just one or a couple of athlete, wheelchair or athlete-wheelchair characteristics (51,53-55,91). A complicating factor in this research topic is the continuous interaction between the three aspects of mobility performance. For example, when the hand rim diameter is increased, the elbow angle becomes sharper. This change can have an effect on the propulsion technique and forces and, therefore, on mobility performance. When the mobility performance changes it is possible that the risk of an injury also changes. As a consequence of the complicated interaction, it is not really known, and difficult to investigate, which of those characteristics have the most impact on performance. The outcomes on the WMP test were used to make a prediction which wheelchair-athlete characteristics may have an effect on mobility performance and can be used in optimization research (Chapter 6).

![Figure 2. Mobility performance in wheelchair basketball consists of three aspects; the athlete, the wheelchair and the environment. These three aspects continuously interact with each other. To enhance mobility performance, focusing is possible on the different aspects related to mobility performance. Examples of possibilities are described.](image)

To determine which characteristics were the best predictors of mobility performance, a prediction study was performed (Chapter 6). Six modifiable characteristics with a potentially predictive value for optimizing mobility performance were derived: the wheelchair characteristics 1) wheel axis height 2) handrim/wheel diameter and 3) camber angle, the wheelchair-athlete characteristics 4) vertical distance between shoulder and rear wheel axis (seat
height) and 5) the vertical distance between the front seat and the footrest, and the athlete characteristic 6) maximal isometric force. The findings of the present study provide coaches and biomechanical specialists with statistical findings to determine on which characteristics they can focus best to improve mobility performance. However, for all characteristics mentioned, it should be determined what their optimal individual values are to improve mobility performance.

The selected characteristics were based on statistical associations between mobility performance and the collected characteristics in a cross-sectional study design. Because of this, the name “predictive” is perhaps somewhat optimistic. One can only know whether a characteristic is actually predictive when it is examined in another design, such as an experimental or longitudinal observation research. Despite this limitation, doing such analyses as a starting-point is very valuable. With this insight, coaches and biomechanical specialists are provided with findings to determine which characteristics they could focus on best to optimize mobility performance.

As a first step towards optimizing mobility performance in wheelchair basketball, the WMP test was used to measure the effects of the characteristics seat height, mass and grip on mobility performance. Despite the fact that mass did not emerge as a predictor, mass was taken into account because the lack of clarity in the current literature during wheelchair propulsion on one hand (5,24,73) and by the ongoing discussion among wheelchair technicians on the other hand. Additional grip was not a characteristic in the prediction study but it was plausible that extra grip on the hand rim has an effect on mobility performance. Besides the presented study in Chapter 7, testing different wheelchair configurations during field-based testing in a sport-specific setting is very scarce. Mason et al. (54,55) have investigated the effects of a sports-specific range of camber angle and wheel size on maximal effort mobility performance in wheelchair athletes. When focusing on the aim “optimizing mobility performance in wheelchair basketball”, further research must focus first on the effect of the characteristics wheel axis height, vertical distance between the front seat and the footrest (bucket seat) and maximal isometric force.

To investigate these characteristics in practice, a multi-adjustable wheelchair can be an alternative for the method used in Chapter 7. The multi-adjustable wheelchair must first be tuned to the settings of their own wheelchair, and from that point, manipulations should be made with the same methodology as used in this study. Note that exact copying of one’s own wheelchair settings (weight distribution/dimensions) is difficult. The current available multi-adjustable wheelchairs have limited possibilities and are not adjustable to all athletes. Although during this research period, the possibilities of a multi-adjustable wheelchair have been considered several times, a design for a solid multi-adjustable wheelchair was not found. Further research is necessary to achieve a multi-adjustable wheelchair for research purposes.
8.4 The individual perfect sports wheelchair

The results of this thesis can contribute to the knowledge to improve the individual sports wheelchair in wheelchair basketball. The results of the defining and quantifying studies in Chapter 2 and 3 provides quantification data to determine field-specific requirements of the wheelchair. For example, during offense, the guards and forwards performed longer driving forward activities than during defense. Based on the data in Chapter 2 and 3 one can state that guards and forwards could benefit more from improved acceleration characteristics of the wheelchair (driving forward) in offensive situations, whereas centers could benefit more from improved stability (standing still). When the responsibilities of a field position are implemented on court, wheelchair changes can influence mobility performance. For example, lower seat heights have been associated with reductions in push frequency, and increasing seat height was reflected in decreased push duration. Therefore, seat height could be a key interface characteristic that may improve the acceleration characteristics of the wheelchair for guards and forwards (58,75,91,94). Furthermore, fore-aft position of the wheelchair-athlete combination influences, as with seat height, the center of gravity and therefore will affect stability (58). Fore-aft position may improve stability characteristics of the wheelchair which could be beneficial for centers.

To increase mobility performance, players have to find the best compromise between the wheelchair adjustments, field position specific requirements and their physical capacity. When it is considered how many compromises are possible to potentially optimize mobility performance, it is clear that further research is required. In the search for the optimal individual sports wheelchair, the described methods and resulting data to define, quantify, simulate and predict mobility performance can be used in the search for optimizing mobility performance in wheelchair basketball. This thesis gives handles to understand the requirements of a match with respect to mobility performance and how to simulate them. With the presented knowledge, extensive and additional research to the effect of wheelchair adjustments can be performed in order to optimize wheelchair basketball performance.

The presented research in Chapter 7 is only a first exploration of limited adjustments on the wheelchair or athlete (seat height, mass and grip) and further investigation should be performed. It is important to know how (all possible) different wheelchair adjustments influence mobility performance. When the effect of multiple adjustments is known, evidence-based choices can be made to enhance the individual sports wheelchair adjustment. To reach the individual perfect sports wheelchair, the individual environmental requirements such as field position have to be included again. This can be done by individual observation of the mobility performance requirements during match play as described in Chapter 2 and 3. It therefore remains a continuous interaction between wheelchair-athlete and environment. For example, a
guard performs a lot of driving forward movements and may choose a lower seat height because this gives him an, for example, 8% advantage in speed. It is possible that this leads to a 5% disadvantage in terms of manoeuvrability. If the roles on court are known, a conscious decision can be made where to aim for. Unfortunately, based on the results in the current studies it is not yet possible to make such considerations in practice yet. However, the described methods can be used as a starting point for further research about the effect of other adjustments on mobility performance. And on another note, systematic and longitudinal monitoring following the methods developed in the current thesis is instrumental to understand wheelchair basketball athlete and team-specific game play and provides stepping stones to improve mobility, athlete and team performances.

8.5 Classification system
In all studies in this thesis, classification is a debated topic. Classification depends on the impairment of an athlete. Wheelchair basketball classification is the system that allows for even levels of competition at team level on the court. Classification plays an important role in the sport as the classification system uses total points of athletes to determine who can be on the court and who not during the game. The individual level of classification is dependent on the limitation-based functional capacity of the athlete (43). Eight classes are defined – ranging from 1.0 to 4.5 – with 1.0 being the class for players with most limiting impairment. This system implies that players with a lower classification perform less compared to players with a higher classification as a consequence of their impairment (and independent of training, skill and talent). The classification system should be reflected in the three performance aspects of athlete performance; game, physical and mobility performance. For all three performance aspects, research was done into the relationship with classification.

The classification system in wheelchair basketball proportionally represents the game performance of the players and it is concluded that that the game performance of elite female wheelchair basketball players depends on functional ability (100, 101). For physical performance, Molik et al. (63) suggests that for the aspect anaerobic performance, no significant differences were found across levels 1-2.5 and 3-4.5 and that the functional classification system should be reexamined. On the other hand, Vanlandewijck et al. (102) studied the relationship between game performance and aerobic power and results indicated significant differences in field performance and aerobic power between Class I and the rest of the classes. Furthermore, De Lira et al. (27) found a correlation between classification and aerobic and anaerobic performance parameters of elite wheelchair basketball players. The relationship between classification and physical performance isn’t clear in the current literature.

During the Wheelchair Mobility Performance test, the performance time on the WMP test was borderline not significant between low (≤2.5) and high class (≥3.0) players (Chapter 4). In a
further analysis, when the classification levels were not grouped, no significant differences in performance time were observed between all the classification levels (Figure 3), which is in contrast with previous research (33,35). In a study of Doyle et al. (33), results of a 20m sprint task shows that class 1 players were significantly slower than players of class 2 and 3 and Gil et al. (35) found also significant correlations between sprinting time and classification. Furthermore, besides the outcome time, kinematic outcomes differed as well between low classified players compared to the adjacent higher-class athletes (83,85). During a match, differences between adjacent classes are even less prominent and the results provided arguments for a reduced number of classes in wheelchair basketball. Based on the kinematic outcomes of mobility performance, a single separation between the current class 1-1.5 athletes and the rest would be adequate (83,85). This recommendation is in line with findings of physical and game performance. However, the results of the relationship between mobility performance time and classification in this thesis didn’t support to split the classification system in two classes.

The relationship between athlete performance aspects and classification is debatable. Further research into the classification system related to athlete performance, should take the three performance aspects together (physical, game and mobility performance). Furthermore, one of the key-settings in the classification system, is trunk function. Use of the trunk is dependent on the impairment of the athlete (1). The trunk can be used in propulsion and players with more trunk function have a higher classification. Information about trunk function and movement during games in relation to classification is not available and recommended (1). Measuring trunk motion during matches with inertial sensors, also recommend during quantifying mobility performance, could be used to explore the relationship between athlete performance and the current classification system.
In conclusion, the available literature about the relationship between performance in wheelchair basketball and classification is not clear. The recommendation to split or reduce the existing classes to two classes (83,85,102) is not supported by the results presented in this thesis. The results in this thesis shows no differences between mobility performance in time and classification level.

8.6 Practical implications
Nowadays, wheelchair basketball is one of the most popular Paralympic sports. Due to the increased professionalism, there is a need for scientific input. This thesis provides a practical pathway to enhance mobility performance, an important performance determining factor in wheelchair basketball. The results of the observation studies in Chapters 2 and 3 can be used to design training protocols. The practical implications of the presented results are that wheelchair-handling training can be the same for all field positions in a team irrespective of playing standard. However, the focus on training differs between playing standards. The difference in standard could be used by national basketball coaches to highlight the wheelchair activities of internationals. This could assist teams to aspire a higher playing standard. Specifically, national teams have to focus more on rotational movements and more on the control option “two hands on the rim” within all wheelchair-movement activities. Coaches should advise players to keep moving to respond quickly to changing situations such as rebounds or opponent actions. Nowadays, the design of training practices should focus on rotational movements and one-to-
one duels, especially for national standard teams. When all teams train on these aspects, the mobility performance during matches will change. In that case it is important to constantly monitor the mobility performance and react on the changes on court with training protocols and wheelchair adjustments.

The developed WMP test can be used in several ways described in paragraph 8.2. In addition to the added value for the wheelchair basketball practice, the WMP test is also valuable for wheelchair technicians. To date, the wheelchair fitting process for performance optimization is highly dependent on the experience level of athlete and the wheelchair technician. More detailed insight in the relationship between key wheelchair adjustments, such as seat height/position and performance could support athlete and wheelchair expert in their decision making. At the moment, evidence-based knowledge of the relationship between wheelchair adjustments is not available. The WMP test can be used as an objective tool to test the individual influence of adjusting settings on mobility performance in order to search for the optimal (individual) adjustment. It is recommended to develop a platform for wheelchair technicians and coaches where they could share their individual results of the different wheelchair adjustments related to mobility performance. In this way, a valuable database will arise which can be used in the search for optimal wheelchair-athlete adjustments.

The used methods in this thesis are not only useful for wheelchair basketball, the described methods in this thesis for defining, quantifying, simulation and prediction can be used as a pathway in several other domains to enhance or test performance. For each sport or domain there are different requirements. To enhance performance, it is necessary to understand these (sport-)specific requirements. After understanding, it should be explored how to measure these requirements in a valid and reliable way. The same applies for rehabilitation and daily life wheelchair users (25,34). To enhance the optimal adjustment of the wheelchair to the athlete, it is recommended to start with exploring the underlying requirements by means of defining, quantifying, simulating and predicting before starting optimizing.

8.7 Conclusions and recommendations

8.7.1. Conclusions

The aims of this thesis were to define, quantify, simulate, predict and optimize mobility performance in wheelchair basketball. The following can be concluded from the studies described in this thesis:

- **Defining** and **quantification** of mobility performance shows that during wheelchair basketball game there are differences in mobility performance between national and international playing standards. Moreover, offense, defense, and ball possession influenced mobility performance during wheelchair basketball games for the different field positions guard, forward and centre.
• To *simulate* mobility performance in a controllable setting, the field-based Wheelchair Mobility Performance (WMP) test was developed based on the observed data from video-analysis. The test can be used as a valid and reliable test to assess the capacity of mobility performance of elite players in wheelchair basketball and to detect changes in wheelchair adjustments. The performance times on the 3-3-6m sprint, the combination task and the overall performance time are recommended to use in both practice and research.

• Six modifiable wheelchair-athlete characteristics were indicated as a *predictor* for mobility performance which could be carried out both in training (maximal isometric force) and in wheelchair adjustment (wheel axis height, handrim/wheel diameter, camber angle, vertical distance between shoulder and rear wheel axis (seat height) and the vertical distance between the front seat and the footrest.

• In a first exploration about *optimizing* mobility performance it was observed that a 7.5% lower seat height increased mobility performance time and no differences in performance were observed with 7.5% extra mass or additional grip.

8.7.2. Recommendations for further research

• **Synchronization** between the used time-motion video analysis, inertial sensor method (kinematic outcomes and trunk movement) and an indoor tracking system to determine field position should be explored to gain a full overview of mobility performance during wheelchair basketball game play.

• The validity and reliability of measuring trunk motion with inertial sensors must be examined in order to gain more information about wheelchair-handling during matches. This method can also provide information which could be used to explore the relationship between athlete performance and the current classification system.

• The possibilities to perform computer-controlled video-analyses with algorithms for action/activity recognition must be studied in order to save time and enable direct feedback to players, coaches and trainer.

• The effect of the wheelchair and fitting characteristics wheel axis height, vertical distance between the front seat and the footrest (bucket seat) and the athlete’s maximal isometric force on mobility performance in wheelchair basketball should be explored first because they are potentially related with mobility performance.

• The possibilities to develop a platform for wheelchair technicians and coaches where they could share their individual results of the different wheelchair adjustments related to mobility performance should be explored.

• To monitor performance in other (wheelchair court) sports or domains, the described analysis method must be applied.